Analyzing the Ohio Valley Region’s Tornado Climatology, 1960-2018

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By

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Abstract

While U.S. tornadoes have been researched intensively by atmospheric scientists and meteorologists, most work has focused on regions like Tornado Alley and Dixie Alley. However, there have been fewer studies focused on the Ohio Valley Region (OVR) that includes Illinois, Indiana, and Ohio. The goals of this research were to create a general tornado climatology of the Ohio Valley region, compare the results to data for the entire United States, and test for changes between inter-comparison normal periods, defined as 1960-1989 and 1990-2018. Data was gathered from the Storm Prediction Center's (SPC) tornado database that contains recordings of all tornadoes from 1950 to the present. For this project, data from two main periods were extracted from the SPC database for analysis: 1960-1989 and 1990-2018. Initially, several different graphs were created using Python scripts to analyze trends in the tornado activity data, including tornado intensities in three different periods (1960-1989, 1990-2006, 2007-2018) and tornado counts in total percentages by month for the two normal periods. Tornado intensities were split into three periods in order to properly analyze the effects of the introduction of the Enhanced Fujita (EF) scale had on rating tornadoes starting in January 2007. In terms of tornado intensity, there have been noticeable shifts in the frequency of weak tornadoes. A net increase of 13 percent was reported in total from 1960 to 2018 of EF/F0 tornadoes across the Ohio Valley. All seasons except for summer saw at least a two percent increase in total tornado occurrences across the OVR. The current peak tornado season in the Ohio Valley matches the rest of Tornado Alley, where the largest number of tornadoes occur from April to June with the majority reported in May. This is a notable difference from 1960-1989 where the peak number of tornadoes were recorded in June. There has also been a recent peak in late season fall (October-November) tornado activity, where 1990-2018 saw 2 percent more tornadoes recorded.

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Introduction

Tornadoes are understudied in the Ohio Valley Region (OVR), defined for this research purpose as Illinois (IL), Indiana (IN), and Ohio (OH). Research has been conducted in hotspot areas for peak tornado occurrences, such as "Tornado Alley" in the Plains states and "Dixie Alley" in the southeastern United States, discussed by Krocak and Brooks (2018). Their research briefly mentions Columbus, OH, and the typical peak for tornadoes to occur around May 15 each year. After this, however, their paper turns to the severe weather climatologies of the Plains and Dixie Alley. Broyles and Crosbie (2004) presented the idea of several smaller Tornado Alleys across the United States, suggesting there are more than just these two areas of peak occurrences. In their research, the Ohio Valley is the third most active region they studied, sitting behind its geographical neighbors: the Great Plains and Dixie Alley.

What neither of these papers nor many others that are published do is consider the Ohio Valley to be a sole focus area in tornado research. As seen with both papers mentioned previously, the OVR is mentioned but passed over for other areas of interest. Much of the tornado climatology data we know is based around areas that do not include the Ohio Valley's recorded tornadoes or synoptic weather patterns. Because of this, it is also not known if the OVR's tornado climatology has patterns or if these frequencies and seasonality of occurrence have changed over time in addition to intensity occurrence. This thesis set out to construct a very basic tornado climatology for the OVR consisting of monthly percentages occurring over two normal periods, along with the intensities for the same normal period. The goal was to analyze tornado databases and look for any patterns (normal or anomalous) that may have formed since 1960, what these patterns could mean and any causes for them, and what our next steps are for a continued tornado climatology for IL, IN, and OH.

Definitions and Background Information

Within this research, I have defined some terms in order to make the resulting comparisons easier to comprehend and follow. First, I used the term “meteorological season” when comparing datasets for the OVR and United States. This means I have defined these seasons to match the standard definition for seasons in meteorological records: “summer” refers to June 1-August 31, “fall” means September 1-November 30, “winter” is December 1-February 28 (29 for Leap Years), and “spring” is March 1-May 31. This ensures that the length of the seasons from year to year remain constant, which would not be if they were defined by the summer and winter solstices and fall and spring equinoxes since these days change yearly.

I will also often refer to the Fujita Scale (F-Scale) and Enhanced Fujita Scale (EF-Scale), the former and current intensity rating systems for tornadoes, respectively. The Fujita Scale was in use from 1971 until 2007, when the Enhanced Fujita scale was implemented to obtain a more accurate intensity rating. The F-Scale used F0-F5, with F0 being weak and F5 being catastrophic, and the EF-Scale maintained this same system, currently using EF0-EF5. Below is a table from NWS Huntsville, with wind speeds and descriptions of each level of tornado intensity, along with pictures from their county warning area (CWA) after the Super Outbreak of 2011 (April 27).

In addition, I refine these ratings down for further simplicity when discussing intensity results. For our purposes, I define tornadoes classified as EF/F0 and EF/F1 as “weak”, EF/F2 and EF/F3 tornadoes to be “strong”, and EF/F4 and EF/F5 tornadoes to be “violent.” This is also in line with some categorization used by National Weather Service (NWS) offices to easier sort and catalog tornadoes for their own CWA.

EF Rating	Wind Speeds	Expected Damage		
EF-0	65-85 mph	'Minor' damage: shingles blown off or parts of a roof peeled off, damage to gutters/siding, branches broken off trees, shallow rooted trees toppled.		
EF-1	86-110 mph	'Moderate' damage: more significant roof damage, windows broken, exterior doors damaged or lost, mobile homes overturned or badly damaged.		
EF-2	111-135 mph	'Considerable' damage: roofs torn off well constructed homes, homes shifted off their foundation, mobile homes completely destroyed, large trees snapped or uprooted, cars can be tossed.		
EF-3	136-165 mph	'Severe' damage: entire stories of well constructed homes destroyed, significant damage done to large buildings, homes with weak foundations can be blown away, trees begin to lose their bark.		
EF-4	166-200 mph	'Extreme' damage: Well constructed homes are leveled, cars are thrown significant distances, top story exterior walls of masonry buildings would likely collapse.		
EF-5	> 200 mph	'Massive/incredible' damage: Well constructed homes are swept away, steel-reinforced concrete structures are critically damaged, high-rise buildings sustain severe structural damage, trees are usually completely debarked, stripped of branches and snapped.		

Table 1: A table that defines and lists characteristics of tornado intensities, along with examples provided from a tornado outbreak (NWS Huntsville 2015).

Data and Methods

The general approach to this project was to find a comprehensive tornado database with enough years of data to create two normal periods of nearly equal length to compare to one another. The Storm Prediction Center (SPC) in Norman, Oklahoma, maintains severe weather reports (hail, wind, and tornadoes), daily count and running annual trend of tornadoes in the United States, and databases containing hail, damaging wind, and tornado counts. The SPC's tornado databases contain data from the last 68 years, spanning from 1950 to 2018. 2019 is not yet included in this data because the number of tornadoes from September through December 2019 have not been confirmed as of February 2020 and are still considered preliminary reports according to the SPC's latest tornado statistics webpage (https://www.spc.noaa.gov/climo/online/monthly/newm.html).

There were two possible U.S. databases to consider using for data analysis of tornado frequencies. Both databases contain the same information which has been submitted by National Weather Service (NWS) field offices and are carefully analyzed at the National Climate Data Center (NCDC) and the SPC (https://www.spc.noaa.gov/wcm/data/SPC_severe_database_description.pdf). These include the magnitude for each tornado, injuries, fatalities, and Federal Information Processing Standard Publication (FIPS) numbers for states and counties where each tornado was located and tracked. The 1950-2018_all_tornadoes compilation is, according to the webpage, a "raw database dump includes all state and continuing county segments", while the 1950-2018_actual_tornadoes compilation contains "single tracks. No state segments or continuing county info." The database containing actual tornadoes was used for this project in order to have a sorted dataset that contained only single tracks of tornadoes; each row in the spreadsheet corresponded to one tornado occurrence, the fundamental data unit used in this research. In addition, any tornado reports given by the SPC were not used in this project, as there can be multiple tornado reports per tornado. This would assume a greater frequency of tornadoes is occurring, even though the actual frequency of tornadoes would be much less than the number of tornado reports per year.

Once a database was decided on, the years to analyze needed to be considered. There needed to be two normal periods in order to take the implementation of new radar technologies into account in addition to having a near equal number of years in each period for an accurate analysis. The purpose of including multiple decades in each period was to help average years with tornado outbreaks and years with very few tornadoes. Modern Doppler radar was in limited production by 1992, and all NWS offices had new radars installed by the end of 1997 (Crum and Alberty 1993). Keeping these criteria in mind, two normal periods of about 30 years were decided on: 1960-1989 and 1990-2018. Several decades are included with each period in order to weed out any anomalies that may have occurred, including the 1965 Palm Sunday Outbreak, the 1974 Super Outbreak, and years where there were little tornadoes recorded. By averaging these frequencies over several decades, it ensured our frequencies were balanced as much as possible. Throughout this project, the 1960-1989 period will be referred to by a few different names, including "the first period", "the first epoch", "the 1960 period"; the 1990-2018 period will also have a few different names, including "the second period", "the second epoch", and "the 1990 period" in order to avoid repetitiveness and distinguish the differences between the time periods.

In addition, there was a third time period created to account for the implementation of a new rating scale for tornadoes. The Fujita (F) scale was updated for operational use and renamed the Enhanced Fujita (EF) scale in February 2007. The Fujita scale was created by Dr. Ted Fujita in 1971 and used wind estimates that were only approximations and never verified by engineers to match the wind speed to the damage expected (SPC, *Fujita Tornado Damage Scale*). In this update, the focus went from only winds (in the F-scale) to including tornado damage and considered how buildings and houses were constructed. The winds were reduced to more realistic levels [an F-5 could have seen almost 300+ mile per hour (mph) winds, the EF-5 rating reduced that to winds of 200+ mph); there are also examples included with damages associated with all six EF levels in order to give the tornado a more accurate rating. The addition of this third period splits the 1990-2018 period into two: 1990-2006 and 2007-2018. This period will only be used when analyzing tornado frequencies by intensity.

Next, the data for the OVR needed to be analyzed through the different time periods and inter-compared with the data for the United States. The database from the SPC was turned into a comma separated value (.csv) spreadsheet for the OVR data. A copy of this spreadsheet was made for the United States data and reduced only to tornadoes occurring between 1960 and 2018. This United States copy was the database used for the comparison with the Ohio Valley data seen in results. Meanwhile, the OVR data was also reduced to 1960-2018 occurrences and was additionally restricted to these tornadoes occurring only in Illinois, Indiana, and Ohio. These two databases were the foundation for data analysis conducted using Jupyter Notebook, a program that relies on a coding language called Python. Python was used to create all histograms seen in Results, as well as a map showing tornado occurrences for both normal periods, 1960-1989 and 1990-2018.

Results

A spatial distribution of recorded tornadoes was created using the previously made OVR database and Python. Figure 1 displays this spatial distribution over the analysis period. Red dots symbolize the 1960-1989 period and the gray dots represent the 1990-2018 period. There appear to be a higher frequency of gray dots overall, a representation that there have been more tornadoes recorded in the recent period than in the previous normal period, indicating a trend upwards in recorded tornadoes. There are also some dots that appear to be out of place, such as being located over Lake Michigan. This is likely due to an error with starting or ending latitudes and longitudes within the database and does not affect the data. While the map shows us a spatial distribution of recorded tornadoes, a further data analysis creating histograms is needed to visualize the temporal distribution between the United States and OVR, and the distribution over the OVR between each of the normal periods.

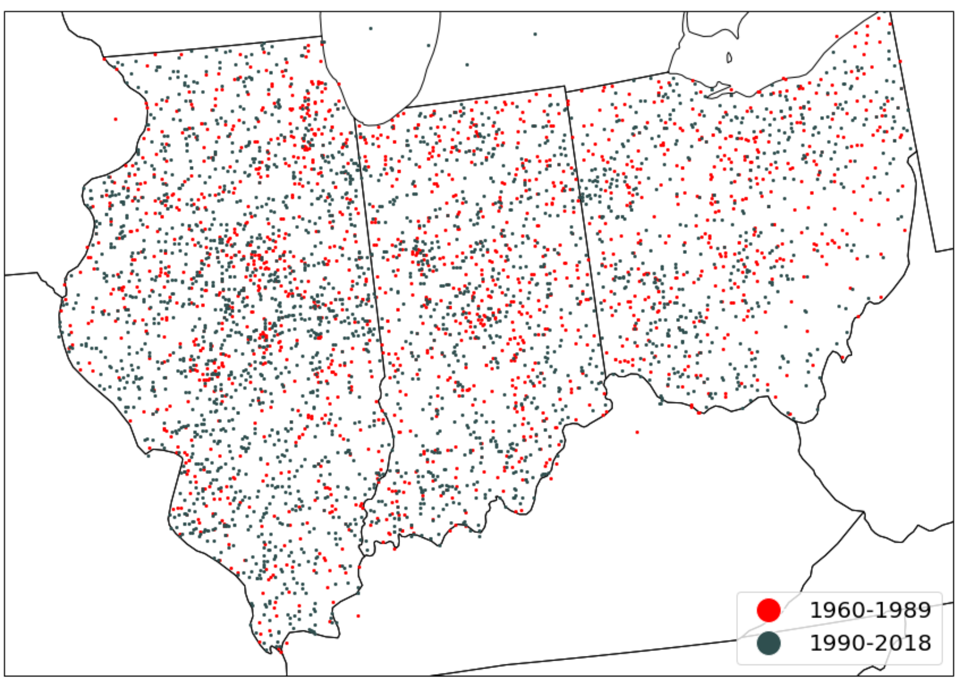

Figure 1: Spatial distribution for recorded tornadoes in the OVR over the research period.

For temporal distributions, histograms were created to first compare recorded tornadoes between the United States and the OVR for both normal periods seen in Figure 2. OVR tornadoes are noted in red, while U.S. tornadoes are in gray and all graphs that follow are measured in total percentage for the decade. This means for example that two percent of all tornadoes recorded for the United States in the 1960 period were experienced in January. The yearly peak for recorded U.S. tornadoes was experienced in May, while the Ohio Valley saw theirs in June. The OVR saw nearly 25 percent of its yearly tornadoes occur during its peak month, while the U.S. experienced about 22 percent. Results for both the OV and U.S. tornadoes followed a relatively normal bell curve as well, except for a slight increase in tornadoes reported for the month of November in the OVR compared to the November tornadoes for the United States.

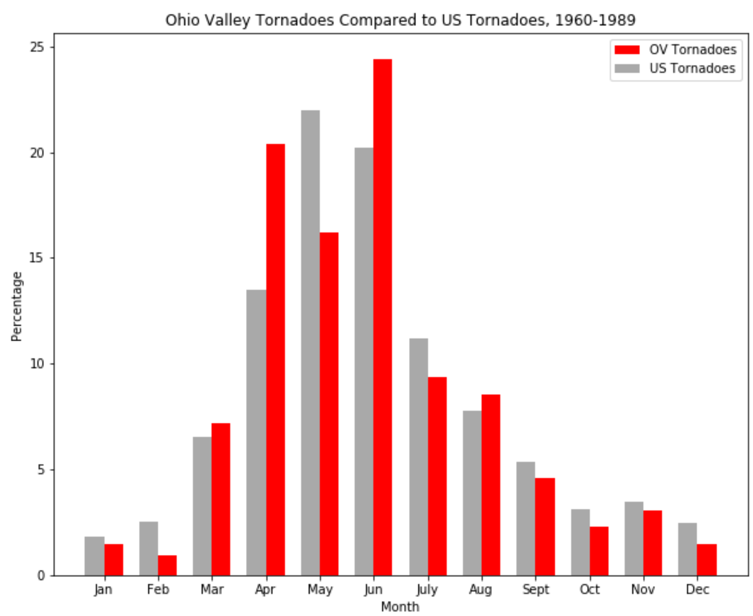

Figure 2: Graph comparing the 1960-1989 tornadoes recorded for the Ohio Valley and U.S.

Next, Figure 3 continues to compare the tornadoes recorded for both the OVR and U.S., this time for the 1990-2018 normal period. This period has a few differences, including a change in the peak of tornado occurrences for the Ohio Valley (previously June, now May). The total percentages of OVR tornadoes for each month are much closer to those percentages experienced of the U.S. as well, with all 12 months being within five percent of each other. Both OVR and U.S. recorded tornadoes follow a smooth curve, except for the month of November for the OVR where there is about a two percent increase in occurrences from October.

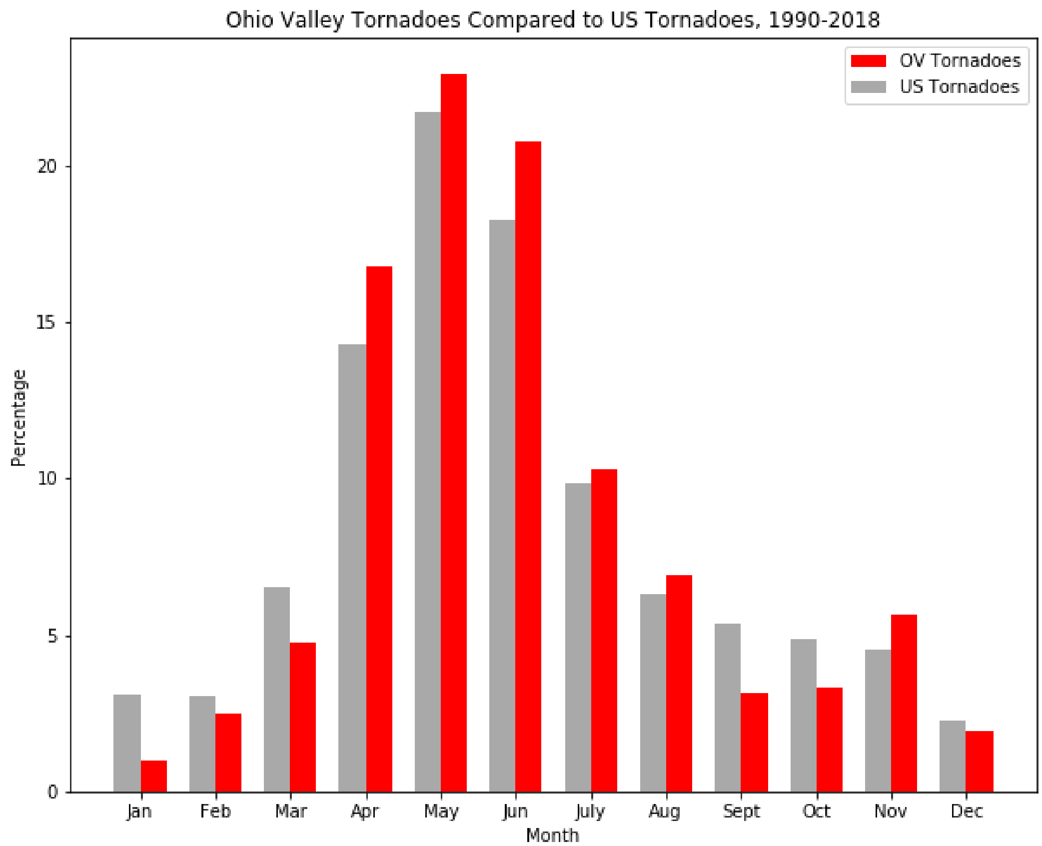

Figure 3: Comparing the recorded tornadoes of the Ohio Valley and U.S. for the 1990-2018 normal period.

Then, the data for the Ohio Valley for both the 1960 and 1990 normal periods were combined into one graph for comparison in Figure 4. The change in month peak occurrence for the OVR is still visible here, but the difference in recorded November tornadoes between the two periods is much more noticeable here; the occurrences seem to double in November and February. There was also an approximately eight percent increase in the total occurrences of May tornadoes in the Ohio Valley from the 1960 period to the 1990 period.

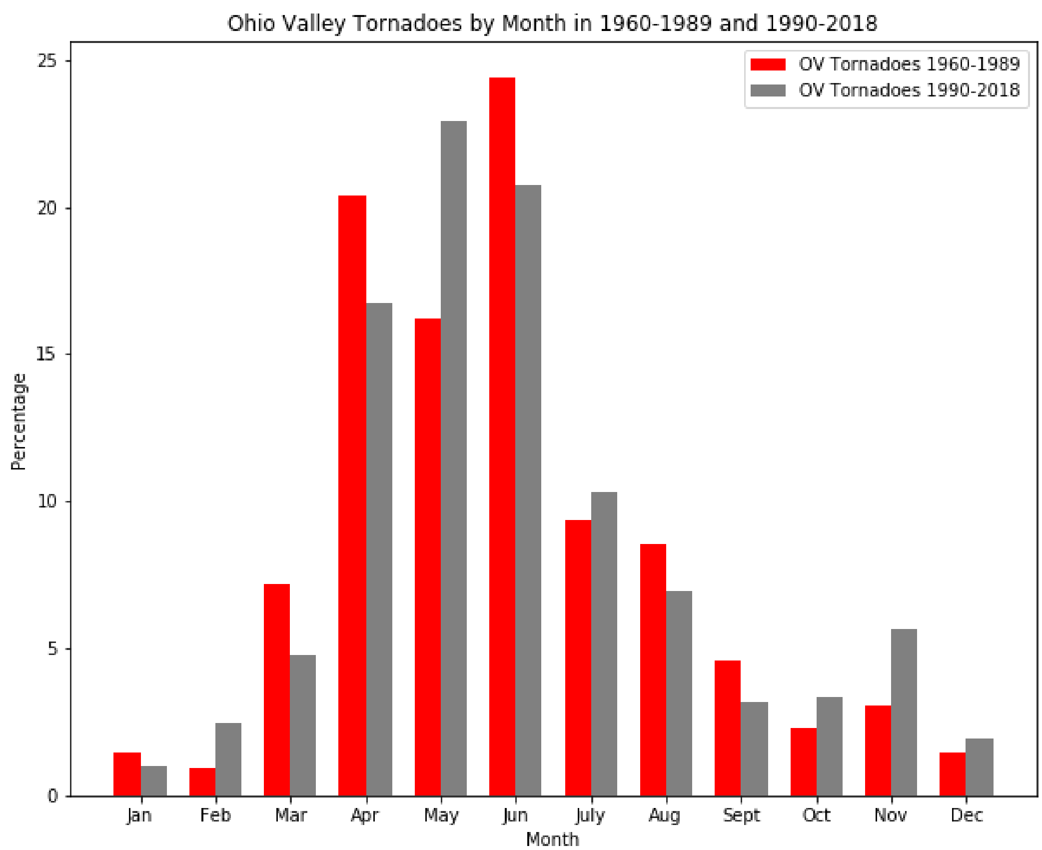

Figure 4: Comparing the Ohio Valley recorded tornadoes for both normal periods.

After comparing the monthly percentages for the Ohio Valley and the United States and inter-comparing the OVR periods, the intensity was the next variable to analyze. Figure 5 follows the same color schematic as Figure 4 where the 1960 period is represented by red and the 1990 period is gray. There was an increase seen in “weak” tornadoes recorded for 1960-1989 from EF/F0 to EF/F1, which then decreases exponentially as the intensity increases. However, the 1990 period starts out with their maximum at EF/F0 recorded tornadoes, decreases slightly as it goes to EF/F1, and has a notable drop-off as the intensity reaches EF/F2 and higher.

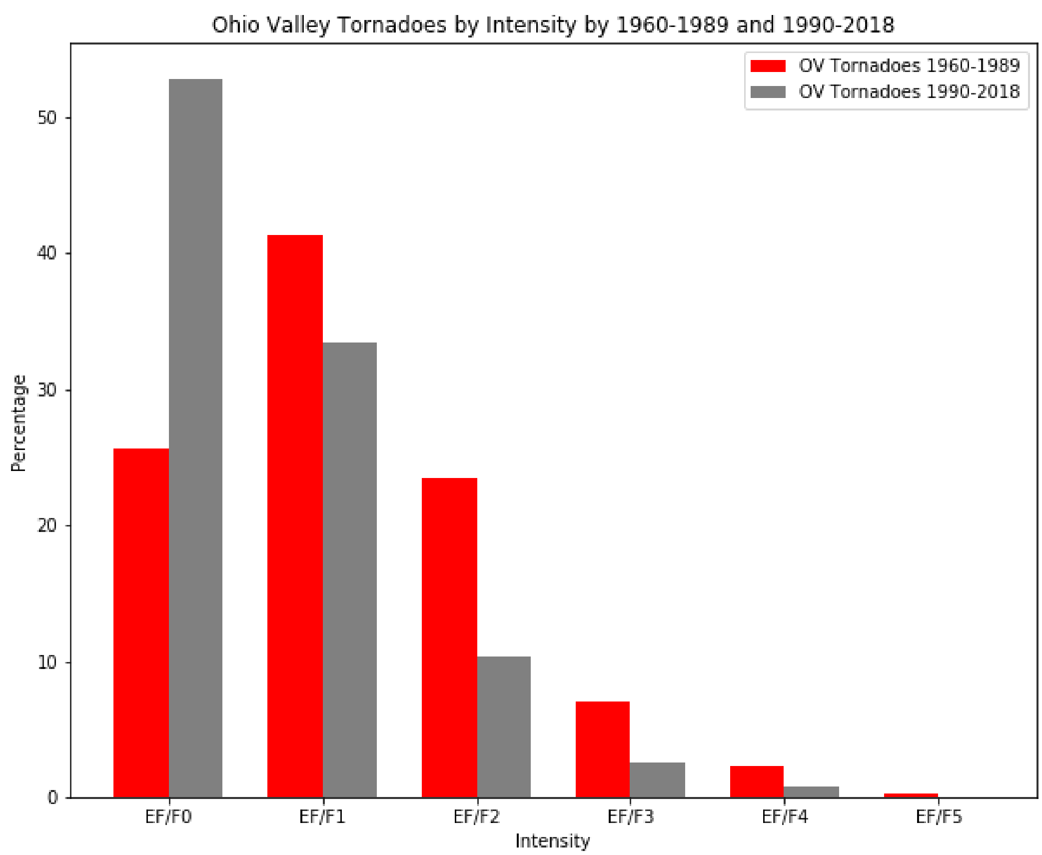

Figure 5: Analysis of OVR tornadoes by intensity in both periods.

From here, the 1990 period was split up in order to account for the implementation of a new rating system for tornadoes, starting in February 2007. The three periods now consist of 1960-1989, 1990-2006, and 2007-2018 for Figure 6. Comparing the 1990 period and the 2007 period, there are still notable increases seen in the EF/F0 intensity, however, there is still a decrease between EF/F1 and EF/F2 reported tornadoes for both periods. There are also fewer strong and violent tornadoes reported in the recent decades, particularly within the 2007-2018 period. There has also been a sharp decline in EF/F5 tornadoes reported as well, with 1990-2006 having very few reports and 2007-2018 having zero reports. Weak tornadoes make up approximately 88 percent of all tornado reports for both the 1990-2006 and 2007-2018 periods, an increase of almost 23 percent from the 1960-1989 period, where weak tornadoes were about 65 percent of all tornado reports. The 1990 and 2007 periods both follow an exponential decline, consist with the decline seen in Figure 5.

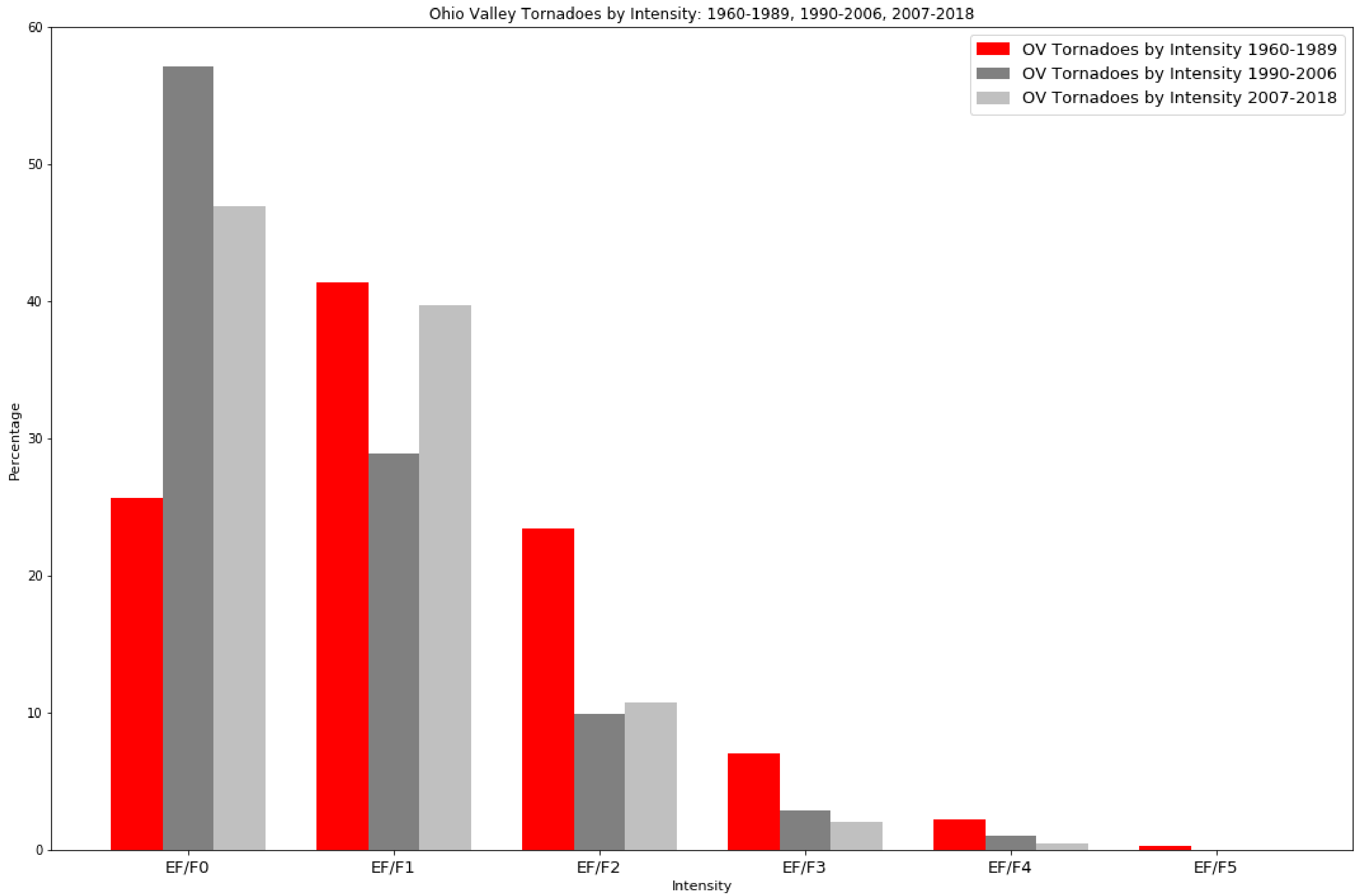

Figure 6: Analyzing OVR tornadoes by intensity for three normal periods: 1960-1989, 1990-2006, and 2007-2018.

Comparing each meteorological season between the OVR and U.S. for 1960 and 1990 periods in Figures 2 and 3 shows us additional talking points for the Ohio Valley. Summer sees a decrease in reports by about eight percent, while winter, spring, and fall all see increases (3.5 percent, two percent, and two percent, respectively). The months to see the biggest increases for OVR from 1960-1989 to 1990-2018 are May, which saw a growth of eight percent, and February, which doubled from 1.5 to 3 percent. The Ohio Valley Region saw a net increase of 13 percent in recorded EF/F0 tornadoes while experiencing net losses in reports for EF/F1 and higher intensities over the three normal periods seen in Figure 6.

Discussion

What are the causes of the fluctuations in tornado reports and intensities in the Ohio Valley over the normal periods? There are two different considerations for why there has been an overall increase of both reported tornadoes outside of peak occurrence in spring and tornadoes of weak EF/F0 intensities. Official tornado reports recorded by the SPC only go back to 1950, when saying the word "tornado" was discouraged or forbidden in order to reduce panic within communities. An official letter explaining this reasoning can be found at www.spc.noaa.gov/faq/tornado/memo1950.pdf. Because of this discouragement, tornadoes were not reported as widely as they are today, along with minimal detection and reporting methods for both the National Weather Service (NWS) and general public. The increase in the number of reported tornadoes could be explained by the creation and implementation of new technologies and new ways of public reporting.

There are a few different technological advances to focus on with the increased tornado totals. Most of these new detection methods and technologies were created after large tornado outbreaks where meteorologists sought to reduce the number of fatalities occurring with large scale outbreaks and increase the warning time on tornado-prone thunderstorms. The 1965 Palm Sunday tornado outbreak is an example of new detection and reporting methods, as it was one of the deadliest outbreaks recorded in the Ohio Valley with 258 deaths across the three states in addition to Iowa, Wisconsin, and Michigan (Fujita et al. 1970). Dr. Ted Fujita provides an excellent analysis of the event along with damage pictures, radar composites, and the synoptic set-up along with research he conducted after his storm surveys, in "PALM SUNDAY TORNADOES OF APRIL 11, 1965". Dr. Fujita created the Fujita scale in 1971 in order to classify tornadoes by an intensity based off wind speed estimates (SPC, *Fujita Tornado Damage Scale*).

However, the Palm Sunday outbreak also led to the creation of the SKYWARN spotter training program, a new way of detecting and reporting severe weather occurring in real time. This consists of classes put on by local NWS offices in each county contained within their warning area during the fall and spring months; most of central Ohio, for example, is located within the jurisdiction of NWS Wilmington. These classes are about four hours long and show the general public how to report severe weather events, including identifying the differences between tornadoes, funnel clouds, and “scud” clouds (clouds that look scary and related to tornadoes but do not contain rotation and are not a threat to the public). Because of this, it is possible the additional volunteer spotters of SKYWARN have contributed to the additional number of tornadoes reported.

Closely incorporated with SKYWARN is the use of social media to report severe weather to NWS offices. In these storm spotter classes, there are examples shown of social media posts used to identify tornado paths, storm movements where large hail was dropped and caused the most damage, and flash flooding on roadways to name a few. Tornado pictures and videos are usually stated with the time each picture or video was taken, along with the closest possible street intersection or town and the direction the camera was facing. NWS meteorologists often combine these reports with Doppler radar to estimate tornado paths and specific locations where storm surveys should be focused. Recently, this was a great resource for NWS Wilmington meteorologists analyzing the Memorial Day 2019 Outbreak affecting southwest and central Ohio, particularly Dayton. Pictures and videos sent to the NWS were highly utilized in determining if more tornadoes had occurred than previously accounted for and led to a few additional tornadoes being added to the total number occurring in the outbreak (Hatzos 2020).

Following the 1965 Palm Sunday Outbreak and the creation of SKYWARN, the 1974 Super Outbreak also saw advances in Doppler radar products and the need for extended Doppler research. Most tornadoes that occurred on April 3rd and 4th were recorded in Illinois and Indiana, but it is also notable how radar impacted detection in Ohio for the F5 tornado reported in Xenia, just southeast of Dayton. Corfidi et al. (2010) summarizes this outbreak in “Revisiting the 3-4 April 1974 Super Outbreak of Tornadoes” and states that tornado warning lead times increased before-and-after the installation of new WSR-88Ds while simultaneously leading to the decrease in fatalities seen within the same time frame studied by Simmons and Sutter (2004).

New Doppler radars were installed across the country starting in 1990 and ending in 1997, benefitting ongoing research efforts to improve detection and advanced warning (Crum and Alberty 1993). New products installed in the mid-2000s through 2013 utilize dual polarization technology, which allows radars to transmit and receive pulses in both the horizontal *and* vertical directions to obtain a better view of the storm environment (NWS, Q&As; NWS Jackson 2017). One of the most popular products among trained meteorologists and amateur storm chasers is correlation coefficient (CC), which shows the difference between objects in a storm system more clearly than previous Doppler radars. CC is used to identify debris balls, typically seen with large and dangerous tornadoes (NWS Jackson 2016). This can help NWS meteorologists verify that a tornado warning is needed, and refine the nature of the threat, especially a Particularly Dangerous Situation (PDS) warning or Tornado Emergency, which are designations usually reserved for strong or violent tornadoes moving towards cities with a larger population (NWS, *Product Description Document*).

Another notable Doppler radar product that has improved tornado detection and tornado warnings is storm relative velocity (SRV). SRV takes a "picture" of the storm and pretends that it is not moving and displays the wind motion (NWS Jetstream 2019) This is used in conjunction with CC to verify if a tornado is on the ground and causing damage, as very strong adjacent winds indicated with storm relative velocity likely mean there is a confirmed tornado. Using SRV can improve the detection of thunderstorm rotation, since using base velocity (another Doppler product utilizing wind direction) can sometimes hide our rotation. Overlaying the storm relative velocity with correlation coefficient and other new Dual-Pol products can nearly guarantee spotting a tornado, even if it is very well hidden.

The Fujita scale, used to classify tornadoes based on their intensity, was replaced by the Enhanced Fujita scale in February 2007 (NWS Huntsville 2015). This new rating scale followed the general layout the F-scale had provided, going from 0 to 5, but changed how meteorologists conducted damage surveys. The EF-scale refined the wind speeds seen on the F-scale and made them much more realistic, while also taking the structural engineering of buildings into account for a more accurate intensity rating. Instead of solely rating tornadoes on a wind speed gust estimate, buildings and structures damaged by a tornado are studied and analyzed to determine what wind speeds could cause the damage seen during the surveys (Edwards 2020, NWS Tallahassee 2018). The winds seen on Dr. Fujita's F-scale were estimates based on a 12-step mathematical process to reduce the thresholds found on the Beaufort wind scale and the Mach number 1 – Roger Edwards from the SPC provides more information about this on The Online Tornado FAQ website, https://www.spc.noaa.gov/faq/tornado/. The winds mentioned in Fujita's F-scale were not scientifically tested before it was implemented and were meant to only be estimates in determining the correct intensity rating. This led to different rating intensities by different meteorologists but continued to be the official rating scale until the EF-scale was introduced (Edwards 2020).

Finally, the use of drone technology on storm surveys is another technological advancement that has improved tornado damage assessment, leading to refined detection and categorization. Drones are used during post-storm surveys, mostly for identifying weak tornadoes and distinguishing the difference between tornadoes, straight line winds, and downbursts. Straight line winds are the winds we commonly see with thunderstorms and are not associated with any rotation, i.e. tornadoes. Downbursts are a general term to describe strong winds pushing down within a thunderstorm (micro- and macro-bursts are the specific terms used to classify the size of a downburst) (NSSL, *Severe Weather 101*) Alignment of damage in drone imagery can assist in distinguishing these linear winds from rotating tornado damage.

It is possible that the increase of over 1,000 tornadoes in the Ohio Valley between the two normal periods is solely due to the detection methods and new technologies listed above. Weaker tornadoes were the most commonly reported tornadoes in the OVR for the 1960, 1990, and 2007 periods, many of which were likely detected through the increased use of CC and SRV. These new Dual-Pol products made it possible more than ever to identify even the smallest rotating couplet on Doppler and attempt to confirm if there is an observed tornado occurring or if it's a strongly rotating funnel cloud. In addition, the number of people wanting to become trained storm spotters through their National Weather Service office is growing and will likely continue to grow. Weaker tornadoes are being brought to the attention of NWS offices because of the increased use of social media within SKYWARN training classes. Pictures of damage – big and small – related to thunderstorms are being posted more often to NWS Twitter pages in the hopes of being mentioned, but what the person may not realize is that the damage picture they captured might be indicative of very weak tornado damage. We see this distinction further captured with drones on storm surveys with being able to take an aerial photograph without the hassle of using a helicopter to gather visual evidence. Drones give us the ability to quickly capture small areas of concerning damage and discerning the difference between a tornado and straight line winds, which could also be very likely for the increase in weak tornadoes recorded in the Ohio Valley.

However, the increase in reported tornadoes could also be due to climate forcing, something we will not likely know for at least several more decades. It is interesting to note that the OVR only saw an increase of about 1,000 tornadoes between the 1960-1989 and 1990-2018 period; is it likely all these new technologies and detections led to ~50% increase in total number of tornadoes recorded in a single region? Perhaps if the increase in this percentage was smaller, say around 10-15%, then it could be highly possible the only reasons for this increase are due to advancing technology. But, since the percentage change is 50% higher between the two periods, it is more difficult to exclude climate forcing from having some effect on the severe weather we are experiencing.

Future Research

This climatology is only the beginning of tornado research in the Ohio Valley Region and lays the foundation for this research to be expanded. As discussed above, if it is possible climate forcing is affecting our tornadoes, it will not be known for decades at the very least. A larger database of climate values such as average monthly temperature and yearly precipitation values will need to be analyzed in combination with this climatology data. The research performed here also does not compare daytime versus nocturnal occurrences of tornadoes in the OVR or how tornado intensities change by season, factors that should be considered in the next few years for data analysis.

Most importantly, there is the opportunity to perform case studies on outbreaks seen in the Ohio Valley. Outside of the popular outbreaks to analyze (1965 Palm Sunday and 1974 Super Outbreak), there are many other outbreaks to perform data analysis on, including but not limited to: November 11th, 2002; June 5th, 2010; March 2nd, 2012; November 17th, 2013; August 24th, 2016. It may be possible to examine the synoptic weather conditions during even older events but most atmospheric data for severe weather events is not archived before the year 2000. In looking at these outbreaks of the 21st century, both weather and climate conditions should be focused on. Examples of weather conditions to focus on would be the position and strength of the jet stream at 300mb, temperature and dew point temperatures measured at the surface and aloft, and positions of low-pressure systems within or near the Ohio Valley. Climate conditions to be considered would include average monthly temperatures and yearly precipitation records as stated above, along with El Niño (warm water) or La Niña (cooler water) conditions in the Pacific Ocean. Even though it would be too soon to guess if climate forcing was changing the tornado conditions in the OVR, analyzing the data listed previously would give us a picture of what weather and climate conditions affect the tornadoes occurring in the Ohio Valley.

Furthermore, this climatology can also be expanded with the help of National Weather Service offices and county emergency managers. Each office and manager would have different needs to fulfill with this climatology so their input would be vital to its continuation. They would also be able to transmit this information to their communities in the ways they feel would be best. This would not mean causing panic for their respective stakeholders by pronouncing that tornadoes always result from similar synoptic conditions, but rather, it will help them become more aware of the tornado probabilities for various conditions, however unlikely. Continued public outreach from both NWS offices and county EMA directors can increase the chances of residents surviving severe weather events by educating them on proper storm shelter locations, practicing tornado drills and having a plan in place for their family, and making them more aware of the difficulties faced by NWS forecasters during severe weather and ensuring resources can be obtained by EMA directors. Although people are generally aware that forecasting is not easy, showing the public more details about the decisions forecasters are forced to make may change their opinion on how they view tornado warnings and other severe weather events.

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